Pleistocene Geology and Unconsolidated Deposits of the Delaware Valley, Matamoras to Shawnee On Delaware, Pennsylvania

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PREFACE

This is a report on the surficial geology of the Delaware River Valley along the northeastern border of Pennsylvania. It was undertaken to study the substantial Pleistocene deposits in an area which will largely be covered by the proposed Tocks Island Dam and Reservoir.

The author has described the features of surficial geology and described in detail the composition of surficial deposits. These features, along with evidence of valley erosion, are related to glaciation which last had an effect on the area about 10,000 to 14,000 years ago during the Wisconsinan stage of the Pleistocene Epoch.

Unconsolidated deposits resulting primarily from glacial action comprise a sand and gravel resource of considerable economic potential. These deposits are outlined and given consideration in the latter part of the report.

A surficial geologic map is a major portion of the report, depicting glacial and alluvial deposits of unconsolidated material and outlining the results of geologic processes active from the Pleistocene Epoch to the present time.

J. P. Wilshusen, Editor

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PLEISTOCENE GEOLOGY AND UNCONSOLIDATED DEPOSITS OF THE DELAWARE VALLEY, MATAMORAS TO SHAWNEE ON DELAWARE, PENNSYLVANIA

by

G. H. CROWL

ABSTRACT

The Delaware Valley was last glaciated during the Wisconsinan stage. The valley slopes were eroded, and the bottom of the valley deeply scoured by ice action. Ice disappeared from the area by stagnation and downmelting, and disappeared last from the valley. Thin till partially mantles the adjacent uplands, and thick glaciofluvial deposits partially fill the valley. Local resurgences of ice movement built two end moraines in the valley, at Dingmans Ferry, Pennsylvania, and near Montague, New Jersey.

The Delaware River valley bottom is a low outwash terrace ±25 feet above river level, about 8 feet above mean flood level, and is covered only by the greatest floods, such as that in 1955. Outwash gravels comprise the bulk of the terrace materials; river silts cover a large portion of the surface. Old river channels mark the surface, and there is one small dune area.

At the base of the valley walls, a discontinuous series of kame terraces appears throughout the length of the valley. They have steeper gradients than the outwash terrace and plunge beneath it in some cases. The kame terraces are not paired; the upstream end of one kame terrace is higher than the downstream end of the next terrace upstream, thus indicating successive terrace formation upstream.

The west slopes of the valley between Bushkill and Matamoras are mantled with colluvium, a shale-chip sharpstone derived from Manhanango Shale outcrops on the slope. Alluvial fans lie at the mouths of some streams.

Gravel reserves are estimated to be several hundred million tons in the kame terraces, and billions of tons in the valley train.

INTRODUCTION

This report describes Pleistocene deposits in the Delaware Valley principally on the Pennsylvania shore, from Matamoras, opposite Port Jervis, New York, to Shawnee on Delaware near East Stroudsburg, Pennsylvania (Figure 1 and Plate 1). At the southwest end, the map area adjoins the Stroudsburg and East Stroudsburg quadrangles. Milena Bucek (1971), cooperating geologist, Pennsylvania Topographic and Geologic Survey, has prepared a

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INDEX MAP DELAWARE VALLEY
(Base from Pennsylvania and New Jersey Geological maps)
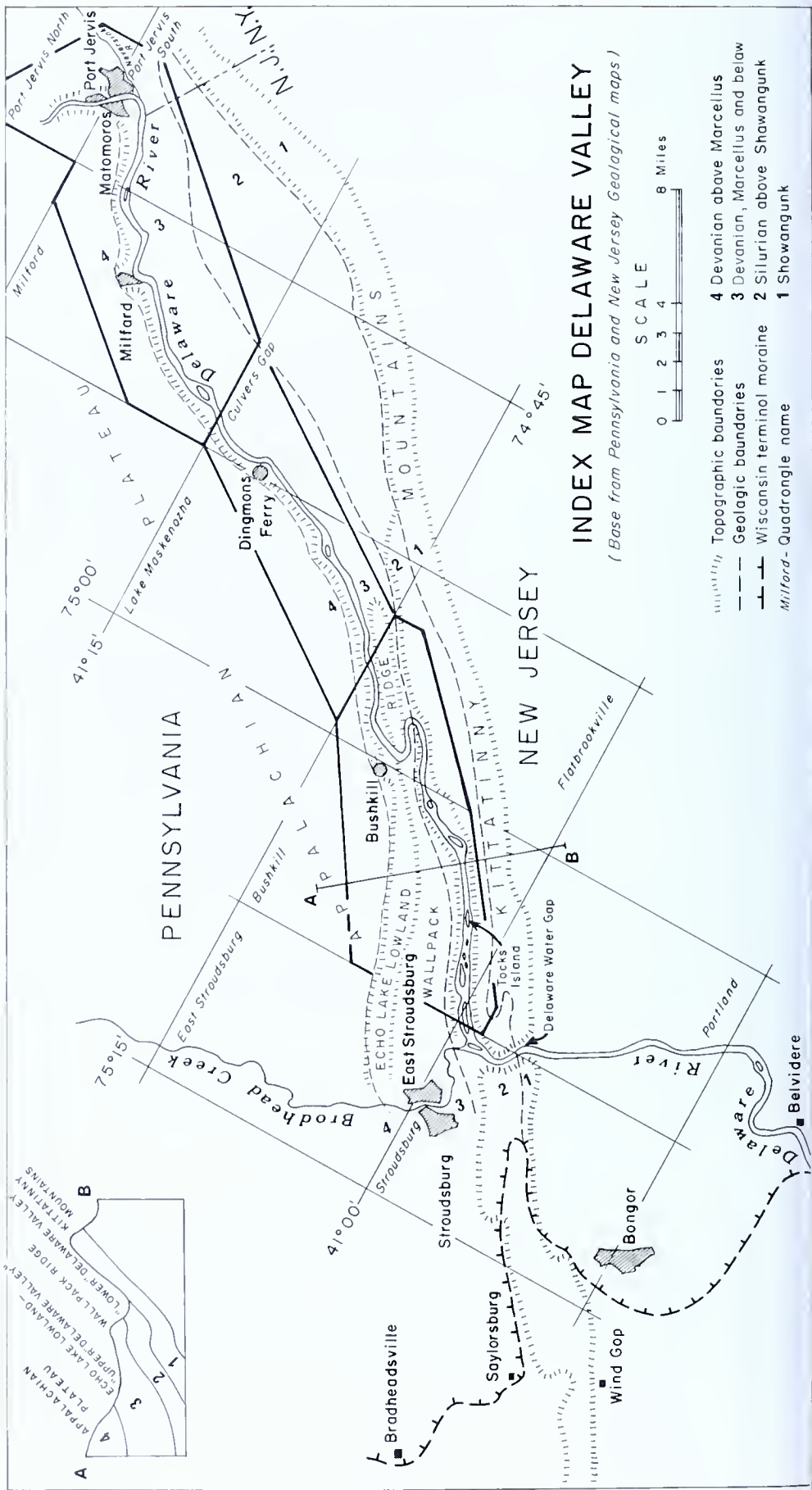
report on the East Stroudsburg quadrangle and J. B. Epstein (1969), United States Geological Survey, has prepared one on the Stroudsburg quadrangle.

The National Park Service, United States Department of the Interior, is beginning the development of the Delaware Water Gap National Recreation Area which will extend from southwest of the water gap northeast along the river to Milford, and encompass land for about a mile on either side of the valley. The Corps of Engineers, United States Army, is proposing to construct a dam at Tocks Island, upstream from Shawnee on Delaware. This will impound water in Delaware Valley and Flatbrook Valley in New Jersey to make a lake which will be the central feature of the Recreation Area. According to the design (Corps of Engineers, 1967), the dam crest will be at 455 feet elevation, and normal pool level at 410 feet. This will pond water to Mashipacong Island above Milford. Flood pool level will be at 432 feet, and this will pond water to Matamoras and Port Jervis. The proposed dam construction and consequent flooding of the valley prompted this study.

Field work was carried on for two months in the summer of 1968 and for a month in 1969. Detailed mapping was confined to the glaciofluvial and alluvial deposits on the Pennsylvania shore and in the Echo Lake lowland extending from Bushkill to Marshall Creek. With one exception, no attempt was made to map bedrock and till outside these areas. A small area of thick till in the southwest corner of the Bushkill quadrangle was mapped to tie with similar deposits in the East Stroudsburg quadrangle. Reconnaissance mapping of the New Jersey and New York portions of the valley was accomplished at the end of the first field season. End moraines in the Milford and Culvers Gap quadrangles have been added as mapped by Salisbury (1902) and Minard (1968).

Deposits were mapped on a topographic base (scale 1:24,000) supplemented by use of aerial photographs. Topographic form and lithologic composition were criteria for delimiting the various deposits. Practically every feature was examined in natural exposure, in road cuts, or by augering to a depth sufficient to determine the underlying materials.

W. D. Sevon, Milena Bucek, J. B. Epstein, D. G. Parillo, and the late Paul MacClintock examined some exposures with me. I am indebted to W. D. Sevon, Paul MacClintock, Gordon Connally, and Jane Forsyth for critically reading an early draft of this report.

PREVIOUS WORK

Lewis (1884) traced the Wisconsinan terminal moraine from Belvidere, New Jersey, west across Kittatinny Mountain at Big Offset in the Stroudsburg quadrangle and demonstrated that this area was covered by the last major Wisconsinan ice advance. Salisbury (1902) mapped the glacial geology of New Jersey and indicated some end moraines within the Wisconsinan drift area. Leverett (1934) mapped older glacial deposits in Pennsylvania beyond

the Wisconsinan border. Ward (1938) argued that Wisconsinan ice did not cross Kittatinny Mountain at the Little Offset, but at some point about 10 miles northeast of Delaware Water Gap; his conclusions have not been accepted by later writers.

Salisbury (1902), Herpers (1961) and Minard (1961, 1968) have mapped fragments of end moraines between Kittatinny Mountain and Delaware River in the area southwest of High Point, New Jersey. MacClintock (1954) mapped an end moraine branching from the terminal moraine in Pennsylvania, crossing the Delaware River at Portland, New Jersey, continuing north across Kittatinny Mountain near Wallpack Bend, and following the base of the plateau escarpment northeast to Port Jervis. Herpers (1961) traced an end moraine from Culvers Gap to the Delaware River at Namanock Island. I found no trace of the moraine cited by MacClintock (1954) in the Delaware Valley; nor did I observe the end moraine cited by Herpers (1961) on the Delaware Valley slopes in New Jersey, and I interpret its "end" at the Delaware River at Namanock Island as an area of kames in the kame terrace. Thus I have followed the mapping of Salisbury (1902) and Minard (1968) in New Jersey.

White (1882) recognized four terraces in this part of the Delaware Valley and their general relation to the glacial history of the area. He described them (p. 49) as made of "modified drift . . . brought to its present position . . . by the Delaware river . . . during the *flooded river epoch* which accompanied the retreat of the Northern Ice cap." I conclude from this statement that he believed these are terraces cut into a valley train.

Salisbury (1902) described the terraces on the New Jersey shore and interpreted their origin as follows: as the ice front retreated up valley, a succession of short valley trains was built in front of each ice stand "to the height of the highest terrace" and the slightly older downstream portion of the valley fill was dissected to form successive flood plains which are now intermediate terraces.

Happ (1938) noted the numerous kame terraces in the Delaware Valley, but regarded the terraces at Milford and Port Jervis as delta terraces built by ice drainage and new stream drainage into lakes on these sites, or alternatively, into one large lake that extended from the Milford area northeast past Port Jervis to Martins Lake in the Neversink Valley in New York.

GEOLOGIC SETTING

The Delaware River occupies a strike valley in Silurian and Devonian formations at the west margin of the Valley and Ridge Province from Matamoras to Wallpack Bend near Bushkill. At Wallpack Bend the river cuts through a hogback of basal Devonian strata and then follows another strike valley in Silurian rocks to Delaware Water Gap where it cuts through Kittatinny Mountain. The scarp slopes of the west valley wall are the edge

of the Poconos, the eastern part of the Glaciated Low Plateau, the easternmost portion of the Appalachian Plateaus in Pennsylvania. The valley is about a mile wide at Matamoras and for several miles downstream; below Milford, it narrows steadily to a half-mile width at Tocks Island.

The Echo Lake lowland is a prolongation of the upper part of the valley and follows the regional strike of the Devonian formations from Bushkill through Marshall Creek to Brodhead Creek above East Stroudsburg. Figure 1 and Table 1 summarize the structure and stratigraphy of the Delaware Valley northeast of the Water Gap.

Northeastern Pennsylvania and northern New Jersey were covered by two, and perhaps more, major ice advances in the Pleistocene. Leverett (1934) in Pennsylvania, and Salisbury (1902), in New Jersey, have mapped Illinoian and Kansan (?) deposits beyond the Wisconsinan border, but none of these has been found within this portion of the Delaware Valley.

Wisconsinan ice advanced southwest over the Catskills (Rich, 1934), south over the plateau (Epstein, 1969), and crossed Kittatinny Mountain in New Jersey to build the terminal moraine through Netcong to Belvidere, New Jersey, on the Delaware River (Salisbury, 1902). Thence the moraine extends in a broad loop to Bangor, Pennsylvania, recrosses Kittatinny Mountain at the Little Offset with a marked re-entrant, and extends northwest through Saylorsburg toward Camelback Mountain (Lewis, 1884; Epstein, 1969). Ward (1938) opposed the accepted views, and argued that Wisconsinan ice did not cross Kittatinny Mountain at the Little Offset, but at some point about 10 miles northeast of Delaware Water Gap. His conclusions have not been accepted by later writers (e.g., Epstein, 1969).

Striae and pebble counts in the Stroudsburg quadrangle indicate a south and southwest movement of the ice in the area north of Kittatinny Mountain (Epstein, 1969). The strong deflection exerted by the mountain is apparent in the westward shift of striae close to the mountain, and in the westward bulge of the terminal moraine north of the mountain.

Topographic control of ice movement in Delaware Valley northeast of the water gap is readily apparent. Basal ice moved directly down-valley, whereas upper ice moved south across the mountain with little deflection. Strike ridges in the valley have been shaped into rock drumlinoids northeast of Zion Church (Bushkill quadrangle) and ledges on the northwest hillsides have been scoured to accentuate the scarp and dip slopes of the beds. The northwest valley wall between Bushkill and Matamoras has been oversteepened and the valley was deepened by ice flow. Subsurface exploration at Tocks Island Dam site shows the bedrock floor at an elevation of 150–170 feet beneath about 150 feet of drift. It is about 100 feet lower at Poxono Island (Corps of Engineers, 1967).

Table 1. *Generalized rock stratigraphy of the Delaware Valley (modified from Epstein and Epstein, 1967)*

	Stratigraphic Unit	Approximate Thickness (in feet)	Description	Topographic Expression
	4* Mahantango Shale	2000	Gray siltstone and silty shale	This forms the valley walls northwest of the Delaware River and Echo Lake Lowland
Devonian	Marcellus Shale		Dark gray silty shale	
	Buttermilk Falls Limestone		Gray cherty limestone and argillite	
	Schoharie Formation		Gray calcareous siltstone	
	Esopus Formation		Gray silty shale and siltstone	These underlie Echo Lake lowland and Delaware Valley northeast of Wallpack Bend
	3 Oriskany Group	1900	Calcareous sandstone, conglomerate, cherty calcareous shale & siltstone	
	Helderberg Group			
	Port Ewen Shale		Gray calcareous shale and siltstone	
	Minisink Limestone		Gray argillaceous limestone	
	New Scotland Formation		Gray shale and limestone	
	Coeymans Formation		Sandy, clayey limestones, and sandstones	This forms the hogback at Wallpack Bend
Silurian	Rondout Formation		Gray shale, limestone, and dolomite	
	Decker Formation		Conglomerate, sandstone, siltstone, limestone	
	2 Bossardville Limestone	2300	Gray limestone	These rocks underlie Delaware Valley below Wallpack Bend
	Poxono Island Formation		Calcareous shale, dolomite, sandstone, and siltstone	
	Bloomsburg Red Beds		Sandstone, shale and siltstone, and minor conglomerate	
	1 Shawangunk Conglomerate	1500	Conglomeratic quartzite, quartzite and argillite	This forms Kittatinny Mountain

* Numbers refer to outcrop areas on Index Map.

PLEISTOCENE HISTORY

Prior to the Pleistocene, northeastern Pennsylvania and northern New Jersey were extensively eroded, and the basic land forms of the Valley and Ridge and the Plateau Provinces were developed. Pleistocene ice sheets advanced over the area from the north and northeast, modifying land forms to some extent, and rearranging some of the drainage. Only Wisconsinan deposits are known in the area.

Wisconsinan ice flowed south over the plateau and was diverted to the southwest in the strike valley of the Delaware River north of Kittatinny Mountain. The valley was scoured to a depth of 150 to 250 feet below present river level. Spurs of the plateau were trimmed away and the valley attained its present broad U-shape. A thin layer of till was spread over the landscape. The terminal moraine extends from Belvidere, New Jersey, in a broad arc to Bangor, crosses Kittatinny Mountain with a sharp re-entrant at the Little Offset thence to Saylorsburg, 13 miles southwest of the map area, and to Camelback Mountain.

With climatic warming at the end of the Wisconsinan, the ice began to melt down at the surface and back at the margin. As the ice sheet thinned motion nearly ceased, and the marginal zone of the glacier stagnated and down-melted in place. Uplands and mountains appeared through the ice, and the ice lingered as tongues and blocks in the valley.

The ice bodies melted more or less independently, creating channels between the ice and valley walls, and ponds by ice dams at various points against the valley walls. Kame terraces began to form in the channels. Their surface slopes and their materials reflect rapid sedimentation in restricted bodies of water with moderate currents. In general, kame terraces at the lower end of the valley formed earlier, and those up-valley formed slightly later with overall retreat of the ice front. Sediment accumulations on the ice were destroyed by letdown as the ice melted, those beneath the ice were destroyed by later stream action, and the kames and kame terraces at the valley-floor margins, which were most remote from direct attack by the river, have survived.

A slight renewal of movement in thick ice, when there was thin stagnant ice southwest of it, led to the formation of the Dingmans Ferry and associated moraines in the broad area between the high valley wall of the Delaware River at Dingmans Ferry and the crest of Kittatinny Mountain to the south. The lower end of the till moraine was buried beneath ice-contact gravels of the "valley choker" moraine in the Delaware Valley.

Down-wasting and accompanying marginal retreat resumed, shrinking the ice tongues in the valley and isolating other blocks of ice. Another slight renewal of ice movement built the moraine at Millville near Montague.

After ice disappeared from this stretch of river, drainage from the area to the north and northeast poured down the valley depositing coarse gravels

and sands to build the outwash terrace. Perhaps the Delaware River was braided as it built the present terrace, certainly it later meandered on the present terrace surface to form meander scars and cut the faces of some of the kame terraces, as indicated by meander scars with about the same radius of curvature as meanders on the Delaware River.

Last of all, the river has incised its channel about 25 to 30 feet, leaving the terrace above the height of the annual flood and developing narrow, discontinuous strips of flood plain along the present channel.

Under periglacial conditions frost action was effective in riving the ice-scoured cliffs of Mahantango Shale. The resulting colluvium mantles the lower slopes and buries some of the glacial deposits at its base.

MATERIALS

Pebbles derived from resistant rocks exposed in Delaware and Neversink valleys and the adjacent plateau comprise the bulk of glaciofluvial sediments in Delaware Valley. Only two "Canadian erratics" were found in the course of the summer's work, one in a kame terrace and one in the valley train outwash.

The material generally ranges in size from sand to cobbles, with occasional boulders. Sand generally comprises 30 percent to 70 percent of the gravel, and seldom occurs as sand beds. The Corps of Engineers (1967) reports lake silts and clays in the subsurface, as shown in Figure 2. Thin beds of these materials are exposed in the midst of outwash sand and gravel near Zion Church and indicate that ponds or lakes were a common feature of the valley train (Figure 3).

Table 2 presents results of pebble counts of representative samples from outwash, kame terrace, and kame materials. The averages, in the last column, are regarded as representative of the rocks of the drift in this size range, and by implication, of all drift material. Replicate samples from the same deposit, and samples from similar deposits and in other locations, show such wide variation that it seems that the general average is the only meaningful figure. Different types of glaciofluvial deposits cannot be distinguished from one another by these counts.

In round figures, Catskill rocks make up 71 percent of the material, Shawangunk sandstones 12 percent, Mahantango Shale 7 percent, and 10 percent of the material comes from Silurian and Lower Devonian formations within the confines of the valley.

The abundance (71 percent) of the Catskill rocks is expected; most of these are well bedded, well jointed, easily quarried, and sufficiently resistant to withstand moderate transport by ice and water. The relatively low percent (12 percent) of Shawangunk conglomeratic and quartzitic sandstone is readily explainable if one recalls that the upper part of the ice flow was in a
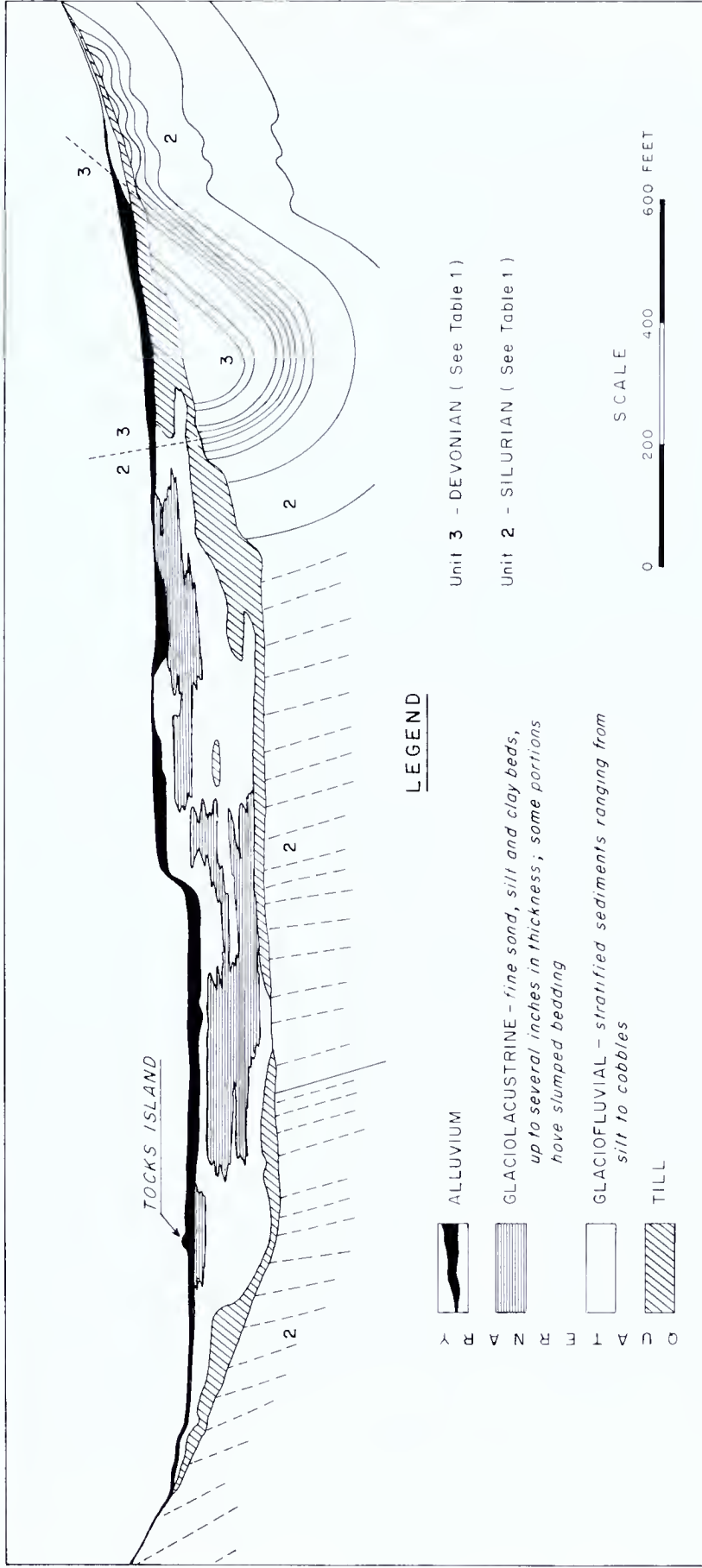
Figure 2. Geologic section of Pleistocene fill at Tocks Island Dam site
(after Corps of Engineers, 1969).

Figure 3. Sand and silt beds in outwash gravels near Zion Church.

southerly direction over Kittatinny Mountain, and basal flow was down the valley. The low amount (7 percent) of Mahantango Shale may result from its relative softness and its highly fractured nature. Judging by its abundance in fine fractions at the Layton Sand and Gravel Company pit, much of it is below the lower size limit of the samples. The low percentage (10 percent) of fragments of Silurian and Lower Devonian rocks which crop out within the valley is surprising. Limestones are very low (2 percent) and this may account for lack of success in attempts to get meaningful figures on depths of leaching in many exposures. Bloomsburg red beds appeared in a noticeable amount in only one count, in the Tocks Island kame terrace (sample 4), and did not appear in the kame terrace at Wallpack Bend (sample 9).

PHYSICAL FEATURES

HILLSLOPES

The hillslope on the New Jersey shore is relatively gentle from opposite Matamoras to Wallpack Bend and is on Devonian rocks. From Wallpack Bend to Shawnee on Delaware the steep valley slope on Kittatinny Mountain is held up by hard Silurian rocks, and approximates a dip slope on northwest-dipping formations. The hillslope on the Pennsylvania shore is generally steep along its whole course in the map area and is a scarp slope on the tilted bedrock.

Table 2. *Summary of Pebble Counts in Glaciofluvial Deposits, Delaware Valley (Samples collected in the 1 to 2 inch size range)*

Material	Kames					Kame Terraces			Valley Train Outwash			
	1	10	11	3	12	4	9	13	8	2	5	Av.
Shawangunk Formation: white conglomeratic sandstone	1	1	5	26	19	6	9	10	12	26	14	11.8
Catskill Formation: coarse-grained sandstone		40	43	17	9	12	46	9	32	2	22	21.0
medium-grained sandstone	11	27	25	10	20	11	24	10	18	7	25	17.0
fine-grained sandstone	14	18	14	13	17	17	17	21	22	34	17	18.6
siltstone	39	4	9	24	13	16	3	17	8	18	7	14.4
Mahantango Shale: iron-rich siltstone	18	10		3	13	1	1	18	3		9	7.0
SUBTOTAL												89.8
Others limey shale	14											1.3
limestone				4	3	7		2				1.5
chert	2		1					1		1		.5
rotten stone			1		3			12	2			1.7
Bloomsburg red coarse-grained sandstone					2	4			1	5		1.0
red medium-grained sandstone	1		1		3	7					6	1.7
red fine-grained sandstone			2			7			2			1.0
red siltstone						6				7		1.2
red limestone						6						.6
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100.3

Sample descriptions and locations.

1. Kame, gravel pit east of Echo Lake.
2. Outwash, edge of terrace near Poxono Island.
3. Kame moraine, Layton Sand and Gravel Company Pit.
4. Kame terrace, pit west of Tocks Island.
5. Outwash, same location as 2.
8. Outwash, edge of terrace north of Depew Island.
9. Kame terrace, Pennsylvania side of Wallpack Bend.
10. Kame, east side of Sand Hill.
11. Kame, south side of Sand Hill.
12. Kame moraine, same location as 3.
13. Kame terrace, pit north of Shapnack Island.

From Shawnee on Delaware to Wallpack Bend, the western slope is on Silurian and Devonian siltstones and limestones. Numerous ledges crop out to give the hillside a stepped appearance readily visible on the ground and on aerial photographs, but not portrayed on the topographic map. Angular limestone boulders are abundant. There are small patches of till on the slope. Where the mantle is thin, it is not possible to distinguish between till, till-derived colluvium, and locally derived bedrock fragments, so consequently the cover is regarded as colluvium.

The Mahantango Shale crops out on the west side of Echo Lake lowland and Delaware Valley from Bushkill to Matamoras. Northeast of Bushkill the valley walls have been oversteepened by glacial scour, and cliffs of shale are exposed at many places. The Cliff, southwest of Milford, is the best example (Figure 4). The base of the slope is almost continuously mantled to heights of 30 to 50 feet by colluvium into which many pits have been opened for light road metal.

The colluvium is a shale-chip sharpstone derived from the highly jointed, gray Mahantango silty shale. Most bedrock exposures of the shale show abundant, closely spaced jointing, and numerous angular fragments of shale on the surface derived by frost action. The angular fragments here and in the colluvium are one to three inches in length, and a half-inch to an inch

Figure 4. The Cliff, southwest of Milford. Mahantango Shale cliff with colluvium mantling the base. Outwash terrace in foreground, kame terrace in midground beneath the house.

Figure 5. Bedding in sharpstone colluvium at base of Mahantango Shale cliff southwest of Dingmans Ferry.

in diameter. Only a few joint blocks, one to two feet in diameter, are visible in most exposures of colluvium. Crude bedding can easily be seen (Figure 5). Bedding dips steeply in the upper part of the deposits and dip decreases steadily toward the toe of the slopes.

Numerous exposures of frost-heaved colluvium beyond the Wisconsinan terminal moraine near Kresgeville and elsewhere attest to a zone of periglacial climate at the ice border. Northward advance of this zone kept pace with downmelting of ice and retreat of the glacier front as the cold climate ameliorated. During this time freeze and thaw action by abundant water in shale fractures must have been effective in riving the rock. The loosened fragments then moved downslope, possibly even as a sludge, to build the talus at the base of the slopes. The talus, at least locally, covers kames deposited earlier between the ice and the valley wall (Figure 6). Several such exposures are visible west of Matamoras and about a half-mile east of Bushkill. No evidence of cryoturbation comparable to that in similar deposits east of Weissport beyond the Wisconsinan border is visible in these deposits. The colluvium apparently accumulated rapidly, for no organic horizons have been observed. Presumably low vegetative growth was established early, to be succeeded by forest growth which stabilized the slopes. At the base of some cliffs today, particularly south of Matamoras, slide rock is invading the forest.
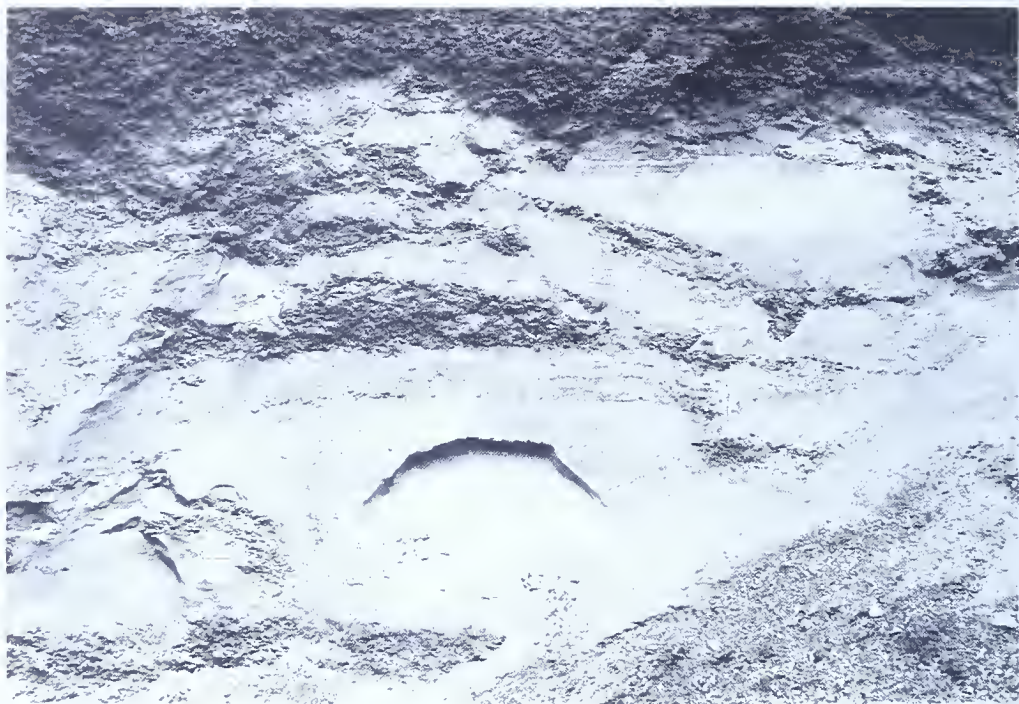
Figure 6. Sharpstone colluvium overlying and interbedded with kame sand at base of Mahantango Shale cliff southwest of Dingmans Ferry. Scale is one foot long.

Till is characteristically a scanty deposit on the hillslopes and is usually less than 8 feet thick. Bedrock outcrops are common on most slopes other than those on Mahantango shale. Locally, till is about 30 feet thick in former depressions on the hill slopes. The Corps of Engineers (1967) has encountered one such body at the New Jersey abutment of Tocks Island Dam. Another such body is being eroded by a tributary stream apparently re-excavating its former valley east of the damsite on the Pennsylvania side. The till is a bouldery, stony, sand till, low in clay, but with many variations dependent upon the underlying bedrock. Till is gray, stony, silty, and sandy on the sandstones and siltstones of the plateau; on Bloomsburg red beds it is slightly clayey and has a reddish hue. It is characteristically drab yellow brown in the weathered zone.

All boulders in the till are from local bedrock; no crystalline erratics were found. Boulders of Shawangunk conglomerate and sandstone are found on the northwest slope of the valley, as well as rocks common to the plateau such as Catskill sandstones. Boulders range up to 10 feet in size, and the largest seem to be derived from nearby outcrops. Most of these are sub-angular; a few are subrounded.

VALLEY FLOOR

The major portion of the valley floor is an outwash terrace about 25 feet above low water level, and ranging between 15 and 35 feet above it. The terrace is flooded rarely, as in 1903, 1936, and 1955. Kame terraces rise above this terrace, and the flood plain is a narrow discontinuous bench or benches cut into the terrace front, 5 to 15 feet above low water level.

The outwash terrace has been mistaken for a flood plain, and the two should be distinguished. ". . . The annual flood (highest discharge each year) will equal or exceed the elevation of the flood plain nearly every year" (Wolman and Leopold, 1957, p. 89). The mean annual flood is one having a recurrence interval of 2.33 years (Tice, 1968).

The mean annual flood at Montague, New Jersey, is 16.8 feet ±2.9 feet, one standard deviation, above gage datum. That is to say, two-thirds of the floods range between 13.9 feet and 19.7 feet above gage datum. This figure is based upon a 26-year record of "normal" floods excluding the August, 1955, flood (Tice, 1968, p. 228). The terrace at Montague is more than 30 feet above gage datum, and 26 feet above summer water level, and therefore above the mean annual flood level.

The Delaware Valley has been subjected to four major floods in the past 130 years. Records for three gaging stations in the area and one downstream with a record of all four floods follow (Parker and others, 1964; Tice, 1968).

Table 3. *Major Floods on the Delaware River (All elevations in feet above sea level)*

Location	Approximate elevation of valley plain	Approximate elevation of river surface	Flood elevations			
			Jan. 1841	Oct. 1903	Mar. 1936	Aug. 1955
Milford, N. J.	130	110	132.5	135.6	133.0	140.1
Dingmans Ferry, Pa.	380	360		384.4	379.6	383.4
Montague, N. J.	390	365		405.4	400.1	405.1
Port Jervis, N. Y.	430	420		438.6	432.9	439.3

Judging from the above records, only these major floods covered any large portion of the terrace. Floods are usually confined to the channel between the terrace fronts. A large number of summer cabins have been built at various places among the terrace front, and in recent years, residents left their cabins and moved to higher ground only in 1955, as the river flooded 8 to 15 feet above the terrace, when Hurricane "Diana" brought extraordinarily heavy rainfall to the eastern seaboard. It seems clear that the valley plain is a terrace, not a flood plain.

The terrace and flood plain are not distinguished on the accompanying map, (Plate 1). The flood plain is too narrow and discontinuous to be

mapped at this scale, for it appears as small patches up to one-quarter mile in length and usually less than 100 feet in width. As noted earlier, flood plain segments range 5 to 15 feet above low water level, and in some cases more than one segment occurs within these limits. Steep natural levees occur locally along the flood plain next to the channel; their growth apparently is accentuated by riparian trees. Where trees are absent, natural levees are lower and more gentle in slope.

The surface of the terrace is flat to gently undulating with a relief of less than ten feet (Figure 7). A swale-and-ridge pattern presumably represents old channels and natural levees. Some of the prominent abandoned channels are shown on Plate 1; locally their courses are emphasized by linear ponds and swamps (Figure 8). The channel at Mashipacong Island northeast of Milford is a good example of an abandoned channel on the modern flood plain; good examples on the terrace are about two miles below Milford, below Dingmans Ferry, and northeast of Bushkill.

With the exception of a sand-and-cobble surface on the Pennsylvania shore at Wallpack Bend, the surface materials of the terrace are fine sands and silts 3 to 15 feet thick, usually massive or with only faint bedding. These overlie sands and coarse, bedded gravels (sub-rounded pebbles about two inches in diameter) with occasional thin lenses of silt and clay. Good ex-

Figure 7. Outwash terrace with kame terrace in background, near Namanock Island.

Figure 8. Abandoned channel on outwash terrace marked by a linear pond and swamp vegetation. Kame terrace in background, southwest of Dingmans Ferry.

posures on the Pennsylvania shore are opposite the lower end of Poxono Island and just above Depew Island (Figure 3). Other exposures are at Tocks Island damsite, about a mile upstream at Pardees resort, and a temporary exposure in foundation excavations for the bridge across the Delaware River for Interstate Highway 84 at Matamoras.

The Corps of Engineers (1967) reports 130 to 150 feet of comparable fill at the damsite. The top of rock thus ranges between 150 and 170 feet above sea level. Hummocky till lies on bedrock and is overlaid by lenticular beds of sand and gravel and local accumulations of fine sand, silt, and clay. Slump structures and ice-rafted pebbles are common in the silt and clay.

The cross section (Figure 2) prepared by the Corps of Engineers (1967) displays the deposits as a sequential fill of outwash from the basal till on the rock floor to the top of the kame terrace at the damsite. The interpretation does not distinguish the kame terrace deposits from the river terrace deposits, even though the two are topographically distinct. Indeed, the materials of the two types of deposits are so much alike that it is impossible to distinguish them in drill holes 150 feet apart, and to draw a boundary between them.

Some layers of gravel in the subsurface are cemented by calcium carbonate. Patches of this and iron oxide cement occur in many of the gravel

deposits. Their sporadic occurrence in relatively coarse and permeable materials indicates deposition by percolating ground water. The carbonate was derived from limestone and the iron oxide from Mahantango shale particles in the drift.

The nature of these deposits—reasonably well bedded, rapidly varying size range, and deposition directly on till—indicates that they are glacial outwash deposited in the valley after most stagnant ice blocks had melted. No precise ice source for these gravels can be pin-pointed now. They could have been swept in from any distance upstream in the Delaware Valley as the ice melted and drainage waters swept down the valley.

Outwash terraces such as this on the Delaware are common in many glaciated regions. The North Fork of the Licking River, north of Newark, Ohio, displays two terraces (Forsyth, 1966) in outwash gravels. De Terra (1943) relates terraces on the Irrawaddy River, Burma, to glacial, interglacial, and post-glacial river regimes. Terrace deposits were laid down during periods of abundant water flow and accompanying heavy load of sediment during glacial stages. This fill was later dissected during non-glacial stages when water flow was lower, and a much decreased sediment load allowed the stream to incise its course into the earlier fill. The mechanism is surely applicable to the Delaware River Valley. As ice melted from this area, braided streams deposited gravel fill to build the valley train to the height of the present terrace. With disappearance of the ice, the river began to meander in normal regime on the valley trains as indicated by correspondence of abandoned meander curves on the terrace with present meanders on the Delaware River. The river has since cut into the valley train to form the terrace and is removing the fill.

An elongate patch of dunes rises 10 to 15 feet above the general level of the terrace about 1.5 miles southwest of Dingmans Ferry. The topography is irregular, with swells and swales in no systematic pattern. The area is now in pasture, but cow paths across the dunes indicate that destruction of the cover would allow movement of the loose sand. This material is distinctly looser than the usual fine sand-silt mixture of the terrace cover. Size analysis of samples from the dune area indicates that, aside from very few pebbles, the material is moderately well sorted and is skewed positively. The mean size is 1.91 ϕ units (0.27 mm) and mean skewness of samples is +0.22. These properties indicate that the material lies within the range of dune sand (Friedman, 1961).

Alluvial fans are located at the mouths of five creek valleys which enter the Delaware Valley on the Pennsylvania shore. They are clearly distinguished by their topographic form. Toms Creek, at Egypt Mills north of Bushkill, has one of the largest fans and it best displays the characteristic fan form. Since its construction, the fan has undergone four periods of downcutting. The stream now flows in a small flat-floored valley near the center

of the fan and above this are three terrace segments which also have the characteristic fan shape, sloping outward from the axis of the fan (Figure 9). Stream channel changes are in progress in the upper parts of the alluviated portions of the valleys above the fan, as in Hornbecks Creek Valley. The floors of Vantine Brook and Vandermark Creek valleys at Milford are alluviated and flat above the kame terrace; recent dissection in the lower courses of these valleys has cut into the terrace. Stream beds are paved with cobble gravel (Figure 10).

It is not easy to distinguish fan-debris from drift, for the fan sediment is derived from drift. The debris has a wide range in size of materials, from boulders through cobbles, pebbles, and sand, to silt, as does drift. Form is the best criterion for distinguishing these alluvial fans.

KAME TERRACES

Kame terraces form a set of discontinuous benches along both sides of the valley (Figure 11). They range up to four miles in length and up to 70 feet above the outwash terrace surface. These are discrete terraces, with surface gradients independent of one another and of the river gradient (Figure 12). Surface form and position above the river terrace best distinguish these from the outwash terrace. They are not paired. Often there is a terrace on only one shore; when terraces are present on both shores they do not match well

Figure 9. High and middle terraces on Toms Creek with kame terrace in background.

Figure 10. Toms Creek, an alluvial fan stream, loaded with cobble gravel, and in process of making a change of course.

Figure 11. Kame terrace above valley train terrace south of Namanock Island, Pennsylvania shore.

in elevation or slope (Figure 12). Thus they appear to be separate entities and not parts of a dissected valley train started at a former glacier margin upstream. They were formed independently, and presumably in rough succession from south to north as the ice melted down and back.

Practically every kame terrace displays sand and gravel on the surface, in natural exposures, or in gravel pits. In few cases was it necessary to drill with an auger to ascertain the nature of materials under a silt cover. Within each terrace, where sufficient exposures are available, there is visible a general and irregular grain-size decrease downstream, from cobbles to pebbles and sand; this gradation is repeated in each terrace and is not continuous from terrace to terrace. The kame terrace on the south side of the Echo Lake lowland east of Shoemakers slopes downward northeast toward the mouth of Bushkill valley, and Sand Hill Creek flows eastward in the depression between the terrace and the hill slope. A pit east of the cross-roads at Shoemakers shows cobbles and boulders; eastward, downstream, sediments change to cobble gravel and then to pebble gravel at the end of the bench.

Where observed, the kame terrace gravels are crudely bedded, and the bedding is flat. Individual beds usually range from six inches to more than a foot in thickness, and an individual bed is a mixture of pebbles, cobbles, and a sand matrix. Thin lenticular beds of sand may be crossbedded. A gravel pit northeast of Shapnack Island shows 20 feet or more of cobble gravel overlying 12 to 15 feet of medium- to coarse-grained crossbedded sand (Figures 13 and 14). The river face of the terrace at Milford shows sandy and bouldery gravel over more than 10 feet of horizontally bedded silt. In each case, the sand and silt is a lake deposit, perhaps in a kettle hole, and gravel was swept in as the lake filled, possibly as current action became more effective, or as sediment source shifted and supply coarsened.

The linear topographic form and the generally coarse sediment indicate that most kame terraces are channel deposits laid down by melt water streams in a depression between the ice edge and the valley wall. After the ice block melted, the ice-contact face of gravel collapsed, and a gravel embankment appeared at the base of the hill slope. Occasionally these terraces form in lakes, or lakes occur in wide parts of the trough, or perhaps in kettle holes on the sites of late-melting ice blocks.

The short kame terraces tend to have a more irregular surface than the long terraces. The kame terrace on the Pennsylvania shore at Wallpack Bend has a marked ridge-and-swale topography, the ridges trending obliquely across the terrace (Figure 15). The ridges mark successive ice-front positions, as the ice retreated from the valley wall and supplied sediment to the kame terrace. Several terraces have a low, broad, flat-topped ridge at the terrace margin and an elongate swale between the ridge and the valley wall or within the terrace. The swales drain upstream or downstream and one or two have been deepened by erosion to shallow valleys at their ends (Figure 16).
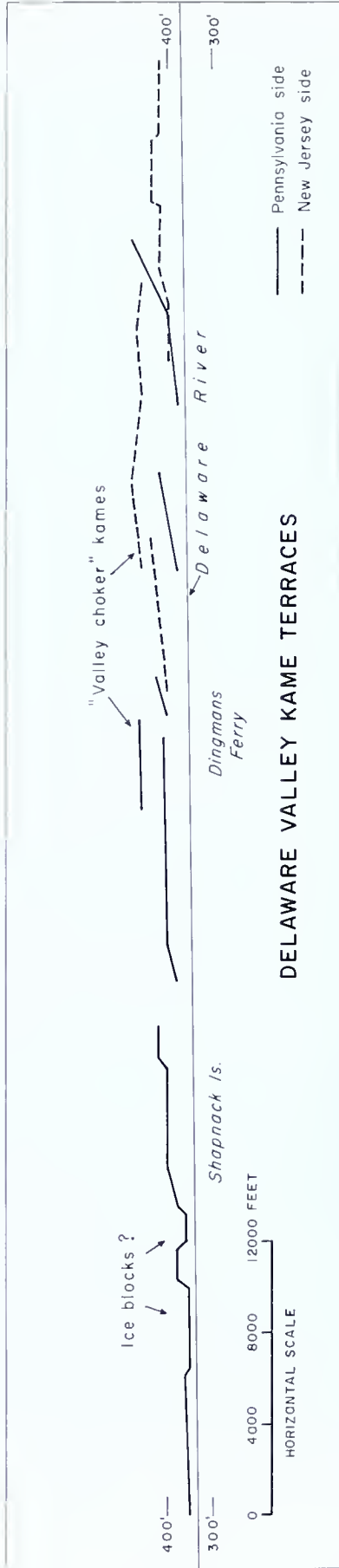
Figure 12. Topographic profiles of kame terraces in central Delaware Valley.

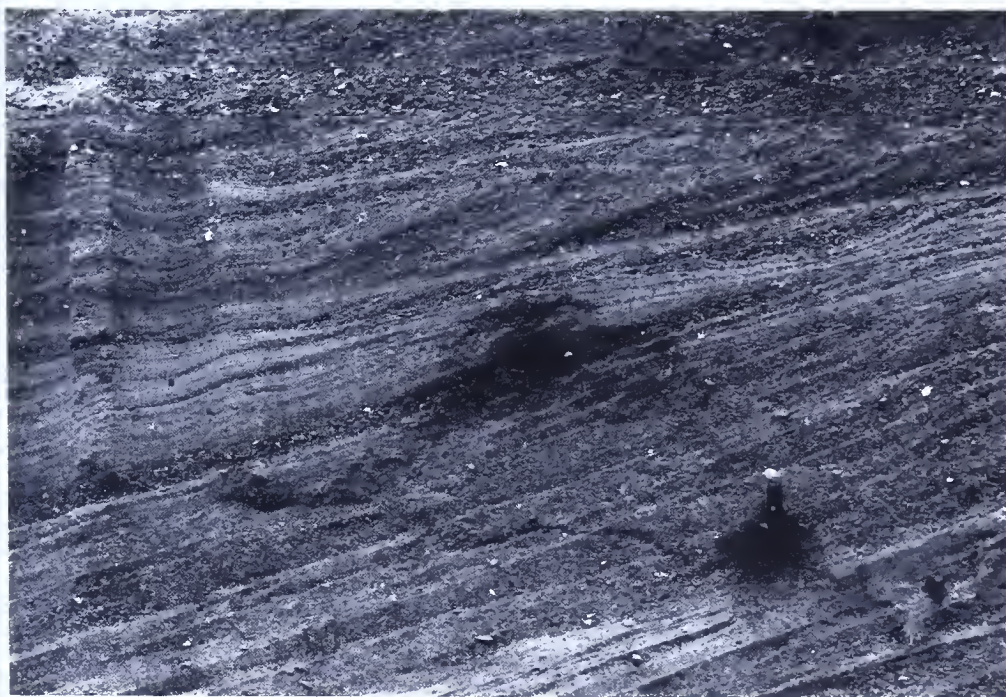Figure 13. Shapnack Island kame terrace. Cobble gravel overlying cross-bedded sand.

Figure 14. Detail of crossbedded sand in Shapnack Island kame terrace. Knife handle is four inches long.

Figure 15. Ridge and swale surface of kame terrace at Wallpack Bend. Surface slopes down to right.

The long kame terraces generally decrease in elevation downstream in irregular steps. The treads of the steps are flat, with a very gentle slope downstream. The risers are steep, and are generally on the upstream side of a marked depression in the terrace. The depression may be a kettle hole, or be open to the face of the terrace (Figure 17). They are the sites of ice blocks which melted out after deposition ceased and supply of sediment to fill the depression was cut off. The difference in terrace height on either side of the depression indicates that the ice block originally formed a barrier to drainage by the alluviating stream, and sediments were deposited to a greater height on the upstream side than on the downstream side. Kame terraces at Tocks Island, Shapnack Island, and below Milford show these breaks in slope (Plate 1).

The most extensive kame terrace on the Pennsylvania shore is that at Milford. It extends from Cummins Creek, opposite Mashipacong Island, past Milford to Minisink Island, a distance of more than four miles. Its surface is nearly flat from Cummins Creek to a mile below Milford where a group of kettle holes marks a break in slope to a lower level. An old gravel pit southwest of here was opened in a high part of the terrace which, because of its height and concentration of coarse boulders, is regarded as a kame within the terrace. Ice melted away from this kame and the terrace was built around it.

Figure 16. Swale in kame terrace above Shapnack Island.

Figure 17. Swale in Tocks Island kame terrace.

Happ (1938) described the Milford terrace as a delta terrace built in the re-entrant in the valley wall where Saw Kill, Van Tine, and Laurel Swamp brooks enter the Delaware Valley. He interpreted the silt and overlying gravel in the river face of the terrace at Milford as lake beds overlain by gravelly topset beds swept in by streams from the plateau. About a mile upstream, the terrace shows cobble gravel and silt over gravel at different locations on the surface, and cobble gravel on the front. An excavation in Milford in 1968, about a quarter-mile northwest of the river face, displayed cobbles about one foot in greatest dimension. These coarse sediments could not have been transported these distances by shallow alluviating streams, nor deposited in ponded water from their postulated source in tributary valleys; sediment must have been derived from adjacent ice.

Happ (1938) also thought that the terrace at Milford and that at Port Jervis were probably deposited by different streams in one large lake extending from below Milford to above Port Jervis. This was based upon similar elevations of the contact between topset and foreset beds. I think that it is unnecessary and undesirable to postulate such a large lake. A kettle hole in the outwash terrace near Milford Consolidated School northeast of the town indicates deposition of the valley train about an ice block. It seems doubtful that this ice block could have survived in the postulated lake and later be covered by outwash gravels.

KAMES

Small kames occur at a number of places within the Delaware Valley
(Plate 1). Most are located at the mouths of tributaries, a few on the valley
walls, and still fewer within the kame terraces. They have been identified
by combinations of position, form, and materials (Figure 18).

Kames within the kame terraces, as at Tocks Island, Namanock Island,
and southwest of Milford, rise above the general level of the terrace and
have a shallow depression between them and the rest of the terrace or the
valley wall (Figure 19). I interpret these rises to mark former ice-edge
positions from which the ice retreated and the terrace was built around the
kame.

A few kames lie on the valley walls with only slight breaks in the slope of
the hill, as at Zion Church. Here the gravel beds dip valley-ward, pre-
sumably let down by melting of the ice wall against which the sediments
were deposited. Very possibly there are many more such small kames, but
where there are no exposures of drift they can be discovered only by
drilling.

Most kames are at the mouths of tributary streams in re-entrants uncovered
as the ice melted down, sites readily available for gravel accumulation from
the ice front or from streams draining the upland and bringing down freshly
deposited glacial material. To the extent that they received upland drainage,

Figure 18. Gravels on surface of kame on Marshall Creek southwest of
Oak Grove.

Figure 19. Kames within the kame terrace, on the New Jersey shore near Namanock Island.

they are stream-built deltaic kames, but the kame a half mile southwest of Egypt Mills, at the mouth of a small valley, is clearly an ice front kame with typical kame structures (Figure 20). Tributaries have dissected the valley mouth kames and have usually left kame remnants on both sides of the valleys. At Egypt Mills, this material, as well as upstream material, has been added to the alluvial fan described earlier.

Kames have been mapped above the mouths of some tributary valleys— Saw Creek, Little Bush Kill, Dingmans Creek, and Sloat Brook at Milford. These show typical kame topography—minor rolls and benches. Few have flat upper surfaces. Gravels crop out in ditches and stream cuts.

The sand and gravel deposit at Millrift on the Pennsylvania shore above Matamoras is mapped as a kame deposit and not a part of the regular kame terrace system. It lies on a rock bench between 420 and 640 feet elevation above the gorge of the Delaware River. Although it has a terrace form showing low downstream-facing scarps, at its lower end it has the typical elevated lateral margin of a valley-side kame. It is composed mostly of sand with minor amounts of pebbles.

The kame complex at Dingmans Ferry is a part of the end moraine represented by Fisher Schoolhouse moraine (Salisbury, 1902) and moraine fragments southeast of Hainesville, New Jersey, mapped by Minard (1961, 1968). It is discussed below.

ECHO LAKE LOWLAND

The Echo Lake lowland lies in the eastern part of a strike valley on Devonian rocks from Bushkill to Brodhead Creek above East Stroudsburg (Figure 1). There is no through drainage. Bush Kill drains the adjacent portion of the plateau, and flows out the northeast end of the lowland to the Delaware River. The central part of the lowland drains west by way of Pond Creek to Marshall Creek, just beyond the map border, and thence to the Delaware River. The lowland is very narrow between Oak Grove and Marshall Creek and widens abruptly into a wide, flat lowland extending west to Brodhead Creek. Marshall Creek cuts across the head of this portion of the lowland, and an unnamed stream drains the western portion into Brodhead Creek. Sand-and-gravel fill provides subsurface drainage for much of this latter portion.

This lowland is not a Pre-Wisconsinan valley of the Delaware River. The rock gap at Oak Grove is too small for the river, and bedrock elevations in the area of Echo Lake range between 440 and 460 feet elevation according to reports by local well drillers. In contrast, bedrock elevations in the Delaware River valley at Tocks Island range between 150 and 170 feet (Corps of Engineers, 1967).

The lowland is floored from end to end with glaciofluvial deposits and ice-block lowlands. Sand Hill, just west of Shoemakers, is a large flat-topped

Figure 20. Kame face southwest of Eagle Mills.

kame with a corresponding kame across the narrow ice-block valley to the north. Its flat top suggests a delta, but typical kame structures on the west and east margins (Figure 21) indicate that it was deposited in a pond between ice blocks which lay in the Werry Lake depression and in Bush Kill Valley. Echo, Coolbaugh, and Meadow lakes are kettle lakes that drain west by way of swamps and Pond Creek. The areas between these depressions and the bordering rock and till slopes are kames and kame plains. The best kame topography is at the east end of Echo Lake; it changes westward to a pitted plain and to a smooth plain which continues southwest to Middle Smithfield Church. A counterpart of this plain lies north of Coolbaugh and Echo lakes. The kame plain is irregular between Wesley Church and Oak Grove; kames and rock hills rise above the surface. The ice contact materials end abruptly at Oak Grove where the lowland narrows; rock and thin till form the slopes of the valley. Beyond this, the lowland widens again and is floored with sand and gravel.

There are few large exposures in the glaciofluvial deposits in the lowland. These few, however, indicate irregular deposition from local sources of sediments in nearby ice. The kame at Oak Grove has abundant cobbles (Figure 22); east of it a low kame shows only sand. Pits in the kame at Echo Lake show cross-bedded gravels and sands, and slumped masses of sand.

Figure 21. Kame face east side of Sand Hills.

Figure 22. Cobble gravel in kame at Oak Grove.

END MORAINES

The Corps of Engineers (1967) has mapped a small end moraine in a little tributary valley on the north slope of Delaware Valley about one mile east of Tocks Island damsite. Although this is tied in with hummocky till lying on bedrock in the subsurface (Depman and Parrillo, 1969), I cannot agree with the interpretation that this is an end moraine.

Till is thicker in the tributary valley than elsewhere on the valley wall, but I interpret this greater thickness to result from filling of a small Pre-Wisconsinan valley. This is the case further east near Zion Church. I take the "bulge" at the base of the hill and the mouth of the tributary to be an alluvial fan, not an end moraine. It is obviously difficult to distinguish an alluvial fan made of drift materials from an end moraine. Perhaps in this instance, shape of the deposit is the best criterion, and this shape indicates an alluvial fan. The deposit is symmetrical and fanshaped in form and does not have a steep distal face and relatively gentle proximal face, like the end moraine near Millville (see below). Nor could I find a moraine on the upland, although there are perhaps more boulders in this vicinity than elsewhere on the ridge.

A "valley choker" moraine complex (MacClintock and Apfel, 1944) occupies the Delaware Valley at Dingmans Ferry. The main mass is a high-

level kame (or kame terrace if one considers the extent and flat top) on the New Jersey shore. A till moraine ridge rises up the New Jersey hill slope from the kame; it rises upvalley, and toward the northeast.

The surface of the kame moraine on the New Jersey shore is about 480 feet in elevation, and slopes upstream and downstream from the lower end of the till ridge. Apparently the kame buries the lower end of the till portion of the moraine. The downstream face of the kame is steep, apparently at the angle of repose. The streamward margin is also steep and is marked by large, deep kettle holes. Upstream, the kame merges with the kame terrace, and opposite Namanock Island another kame ridge rises above the general level of the kame terrace.

On the Pennsylvania shore the main mass of the kame moraine is east of Dingmans Ferry and is about 460 feet in elevation (the topographic map omits the hill here). The rest of the kame system is a set of valley-mouth kames where tributaries enter the valley in the stretch from Dingmans Creek upstream to Indian Point.

These kames are 60 to 80 feet above the kame terraces downstream, and merge with the terraces upstream on the New Jersey shore. They are higher and older than the kame terraces and are mapped independently of them even though they have a terrace form. The kames are separate now and presumably were so when formed, although the kame at Dingmans Ferry appears to have been trimmed by river action, and the river may once have flowed through the gap which is now the site of the village.

The Layton Sand and Gravel Company pit near the lower end of the moraine on the New Jersey shore exposes crudely bedded, sandy, cobble gravel with about 30 percent sand (Figures 23, 24). Sand lenses and layers are a minor part of the total exposure. There is at least one concentration of small boulders on the surface, and an exposure near Dingmans Ferry School shows cobble gravel coarser than much of that seen across the river. The beds of cobble gravel exposed in the Layton pit indicate a long period of sedimentation by high-volume streams. The flatness is a reflection of the large area of deposition.

The abrupt downstream end of the kame moraine is ascribed to deposition in a basin partially blocked by dead ice at the downstream margin; the kettle holes on the west margin (Plate 1) are indicators of such blocks. The resemblance to Sand Hill in Echo Lake lowland is close, but here all trace of the former ice blocks has been removed by later construction of kame terraces and the outwash terrace. The kame terraces are almost continuous along the river in the passage between the kames, and the outwash terrace below them is restricted. Upstream, the kame terrace is high on the new Jersey shore because drainage was impeded by the kame moraine.

The till moraine ridge rising from the kame moraine is the Fisher Schoolhouse moraine of Salisbury (1902). It is a till ridge rising northeast obliquely

Figure 23. Gravels in kame moraine at Layton Sand and Gravel Company
            pit northeast of Dingmans Ferry.

up the hill slope to just beyond the crest of the hill where it dies out. The
moraine is a ridge about 30 feet high with a steep slope on the south side
where a moraine-front stream flows down the trough to the kame and
along its valley-wall margin. The northwest slope of the moraine descends
steeply from the crest to a belt of irregular ridges and depressions on the
hill slope.

This moraine probably correlates with end moraine segments near
Hainesville, as mapped by Salisbury (1902) and Minard (1961, 1968).
Reconnaissance on the plateau above Dingmans Ferry has disclosed no
counterpart of this moraine. Till deposits are thicker here in the headwater
areas of streams flowing to the Delaware River than on the upland. These
do not constitute an end moraine; they indicate greater deposition of till in
depressions. A small area of rolling topography on Pa. Route 739 north of
Silverthread Falls on Dingmans Creek (Lake Maskenozha quadrangle)
resembles end moraine, but it is only locally thick drift that partly masks
strike topography on Mahantango Shale. One of the ridges is an esker lead-
ing down to the drainage; it is so short that transport distance was insufficient
to round the pebbles.

The Millville end moraine is on the New Jersey shore about a half-mile
upstream from Millville, opposite Milford. It starts as a narrow till ridge
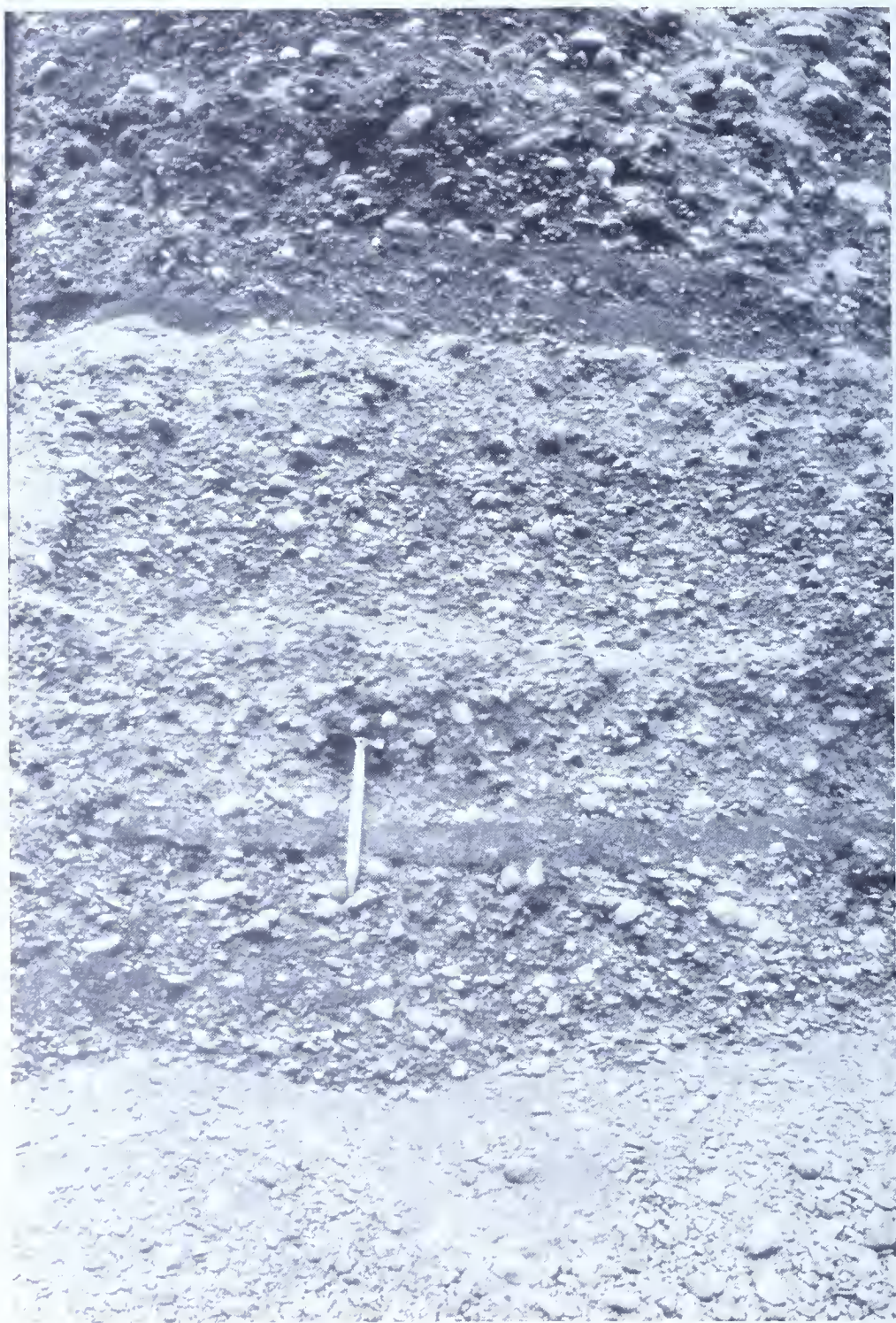
Figure 24. Detail of Figure 23. Pick is eighteen inches long.

near the crest of the rock ridge, widens down into the valley, and lies between two portions of the kame terrace. It ends abruptly where a former course of the Delaware River on the stream terrace trimmed it and the adjacent parts of the kame terrace. The proximal slope is relatively steep, and the top slopes gently downstream. The distal slope may be steepened by a moraine-front stream between it and the adjacent kame terrace. Large boulders, one to three feet in long dimension, are more numerous on the moraine than elsewhere in the area, particularly the kame terraces. Augering to shallow depth shows what I consider to be sandy till. The surface boulders, the asymmetrical form, and the ridge up the valley slope are the best indicators that this is an end moraine marking the temporary position of an active ice front. This moraine is much less prominent than that at Dingmans Ferry. It is apparently a part of the moraine at Montague, New Jersey, which continues eastward to Kittatinny Mountain (Salisbury, 1902; Minard, 1961, 1968).

Hurried reconnaissance on the plateau above Milford shows high-level coarse-gravel kames on U.S. Highway 6 in the vicinity of Vantine Brook. These may be a part of a kame moraine on the upland.

MacClintock (1954) has mapped an end moraine at Sparrowbush, New York, but its presence has not been verified, nor has its counterpart been found on the Pennsylvania shore.

AGE OF THE DRIFT

Drift in Delaware Valley is Wisconsinan in age. In western Pennsylvania and New York, west of the Salamanca re-entrant, the Wisconsinan "terminal moraine" is made of Kent drift (Shepps et al., 1959; Muller, 1963). In Ohio, this drift is about 23,250 YBP (White, 1968) and is early Wood-fordian (late Wisconsinan) in age. The Titusville Till, about 31,000 YBP lies between the Kent Till and Illinoian drift to the south, and is considered to be Altonian (early Wisconsinan) in age by White and Totten (1965). The Kent drift border has been traced eastward about 70 miles from the Salamanca re-entrant to Almond and Bath, New York (Muller and Connally, 1968).

On the east side of the Salamanca re-entrant, Olean drift (MacClintock and Apfel, 1944) lies south of the Kent Till, and its southern boundary is the Wisconsinan "terminal moraine" traced into eastern Pennsylvania by Lewis (1884). Because it is older Wisconsinan than Kent drift, it is probable that the Olean drift, in its type locality, is Altonian in age. MacClintock (1954) correlates the drift inside the terminal moraine in Delaware Valley with the Olean drift in the Salamanca re-entrant in western New York (MacClintock and Apfel, 1944). The terminal moraine is traced eastward across New Jersey to Long Island where it is generally correlated with the

Harbor Hill and Ronkonkoma Moraines which are considered to be Wood-fordian in age (Muller, 1965; Schafer and Hartshorn, 1965). Thus it appears that the terminal moraine is not the same age throughout its length from the Salamanca re-entrant to Long Island.

Radiocarbon dates on basal organic material from Leap's Bog, near Oak Grove, and from Echo Lake, about 20 miles north and east of the terminal moraine, are given in Table 4.

Table 4.   *Radiocarbon Dates.*

Leap's Bog
   Sample Number

OWU—413	organic material 8 cm above clay.	9563 ± 212
OWU—414	organic material 2 cm above clay.	9900 ± 216
OWU—415	clay gyttja.	12521 ± 829
I–3929	wood next to mastodon	12160 ± 180
I–3930	bone in limey mud	10020 ± 180

Echo Lake
OWU—439	silty clay gyttja	13233 ± 1618

These dates are internally consistent, and indicate a minimum age of 10,000 to 14,000 YBP for the beginning of organic sedimentation in this area. Mickelson (1968), on the basis of dated marine beds in Maine and dated bottom sediments in a bog in a marine delta, estimated an interval of about 2000 years for disappearance of ice and beginning of organic sedimentation in a kettle. Florin and Wright (1969) conclude that it is not yet possible to estimate the time involved in the melting of an ice block, but they estimate a range of 350 to 5000 years between emplacement of ice and beginning of organic sedimentation in kettles in Minnesota. It seems unlikely that it would have taken more than 2000 years for ice to melt from these kettles in the Echo Lake lowland. Thus drift in Delaware Valley can hardly be Altonian in age, but its stratigraphic position within the Woodfordian is uncertain. Solution of this problem must await further mapping of the border zone, till analyses, pollen analysis of bog sediments, and radiocarbon dating of organic sediments whose stratigraphic position is better known.

MINERAL RESOURCES

The mineral resources of Delaware Valley are glacial sand and gravel, and shale-chip sharpstone derived from the Mahantango shale. The current acquisition of land for the National Recreation Area removes the Delaware Valley reserves from the possibility of exploitation in the near future. It is possible that gravel reserves in the reservoir area may later be exploited by dredging, without marring the landscape.

There are numerous small pits in the Mahantango sharpstone colluvium throughout the length of the valley. They operate sporadically, their total production is judged to be very small, for local use only as fill and for road metal on driveways and secondary roads.

The gravel resources of Delaware Valley in kames, kame terraces, and valley train are estimated to be in the hundreds of millions of tons. Estimates of volumes in kame terraces between Tocks Island and Dingmans Ferry and in the kame moraine, based on planimetered areas and estimated heights above river level are given below (Table 5). Tocks Island kame terrace is not included because it is at the dam site. Kame terraces up river from Dingmans Ferry are not included because they are at or above the proposed water level of the reservoir, and are judged to be unavailable for exploitation.

The kame moraine on the New Jersey shore contains 42 percent of the gravel reserves, and Shapnack Island kame terrace 24 percent. The pebbles and cobbles are about 85 percent sandstone, 7 percent Mahantango Shale, 6 percent siltstone, and 2 percent limestone and chert (Table 2). Prior to any large-scale development, a deposit should be thoroughly tested to determine that its products will meet market specifications and provide the desired size ranges.

Table 5. *Estimated Gravel Reserves in Kame-Terraces and Kame-Moraines*

Kame-terraces	Vol. in millions of cu. yds.	Materials Percent (estimated)		
		Sand	Pebbles	Cobbles
1 Wallpack Bend, Pennsylvania shore	12.0	50	40	10
2 Shoemakers	1.5	50	40	10
3 Bushkill	18.0	50	30	20
4 Shapnack Island	35.5	70	15	15
5 Dingmans Ferry	5.5	75	20	5
6 Milirift	30.0	60	30	10
7 Echo Lake Lowland	37.0	60	25	15
Dingmans Ferry Kame-moraine				
Pennsylvania shore	8.5	30	60	10
New Jersey shore	62.0	30	60	10
Kames				
Sand Hill	15.5	80	15	5
	225.5			
Valley train between Tocks Island and the kame-terraces upstream from Depew Island (includes Pennsylvania and New Jersey shores)	1120.0	85	10	5

Even casual examination of the map (Plate 1) indicates that the area o
the kame terraces is only a small fraction of the area of the valley train. The
average height of kame terraces above river level is about 50 feet; the depth
of fill in the valley at Tocks Island is about 150 feet and is probably no
much less at Dingmans Ferry. Thus the gravel reserves of the valley train
are many times those of the glaciofluvial deposits.

The Layton Sand and Gravel Company, Layton, New Jersey, operate
the only large active gravel pit in the valley above the water gap at the
present time. According to Mr. Coddington, plant superintendent, abou
70 percent of pit run is pebbles and cobbles, and about 30 percent sand. The
plant produces about 140,000 tons of aggregate per year. The pit run i
crushed and sized to sand and grades of gravel ranging up to $\frac{3}{4}$ inch size
The plant markets in the area from Bushkill to Port Jervis, New York, and
Andover, New Jersey.

One other pit in the area is active, and produces pit run sand from :
kame east of Echo Lake. Other small pits are inactive, and apparently hav
produced only pit run sand and gravel.

The mineral resources of the valley are being exploited at only a smal
fraction of their ability to produce over a long period of time. However, th
economic needs of a growing population in the Mid-Atlantic Seaboard
oppose the preservation of the natural landscape. It is a problem that wil
grow more insistent for solution. Sophisticated economic and politica
solutions must be found for the problems of conflicting uses for this are
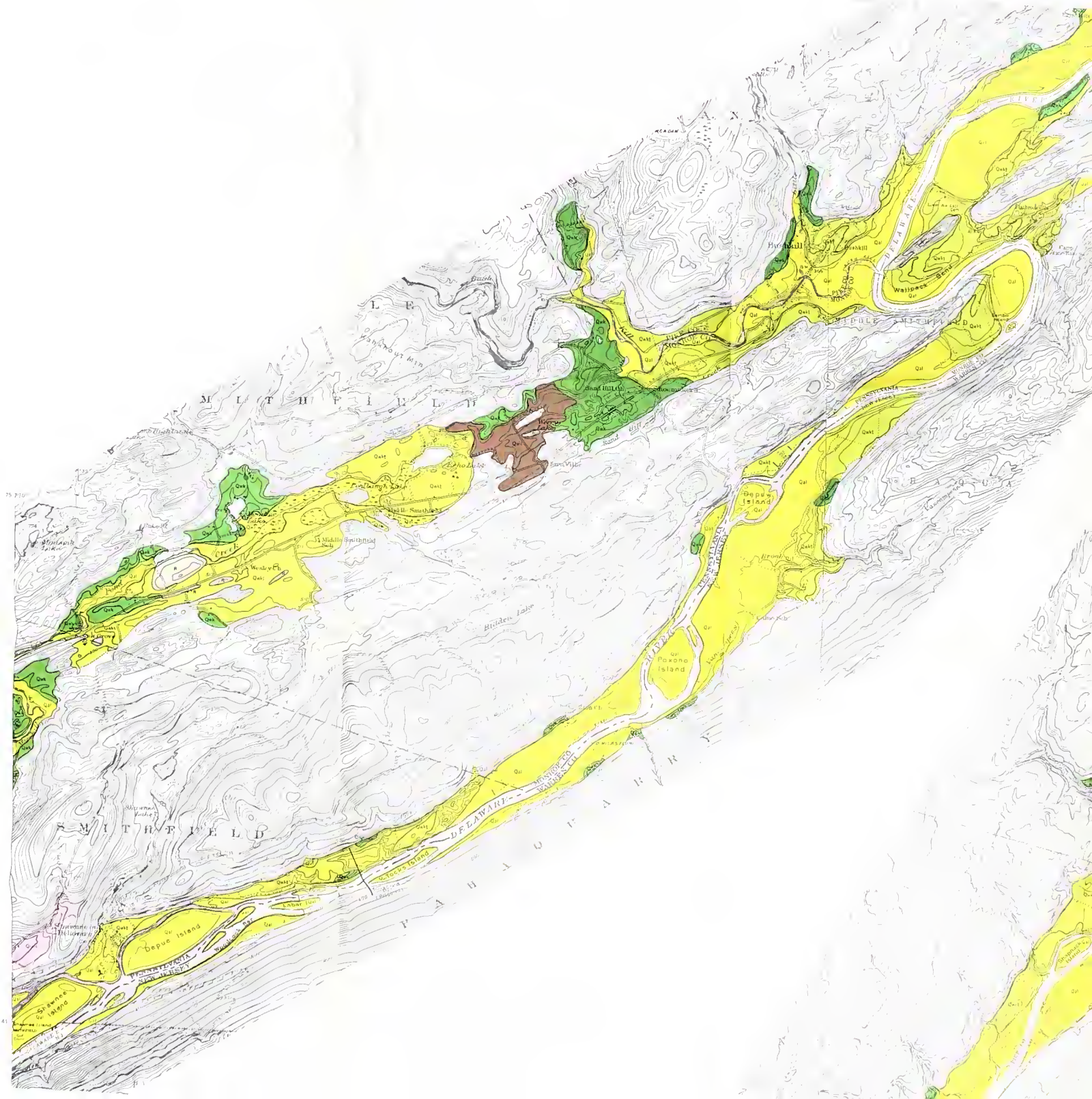and its resources.

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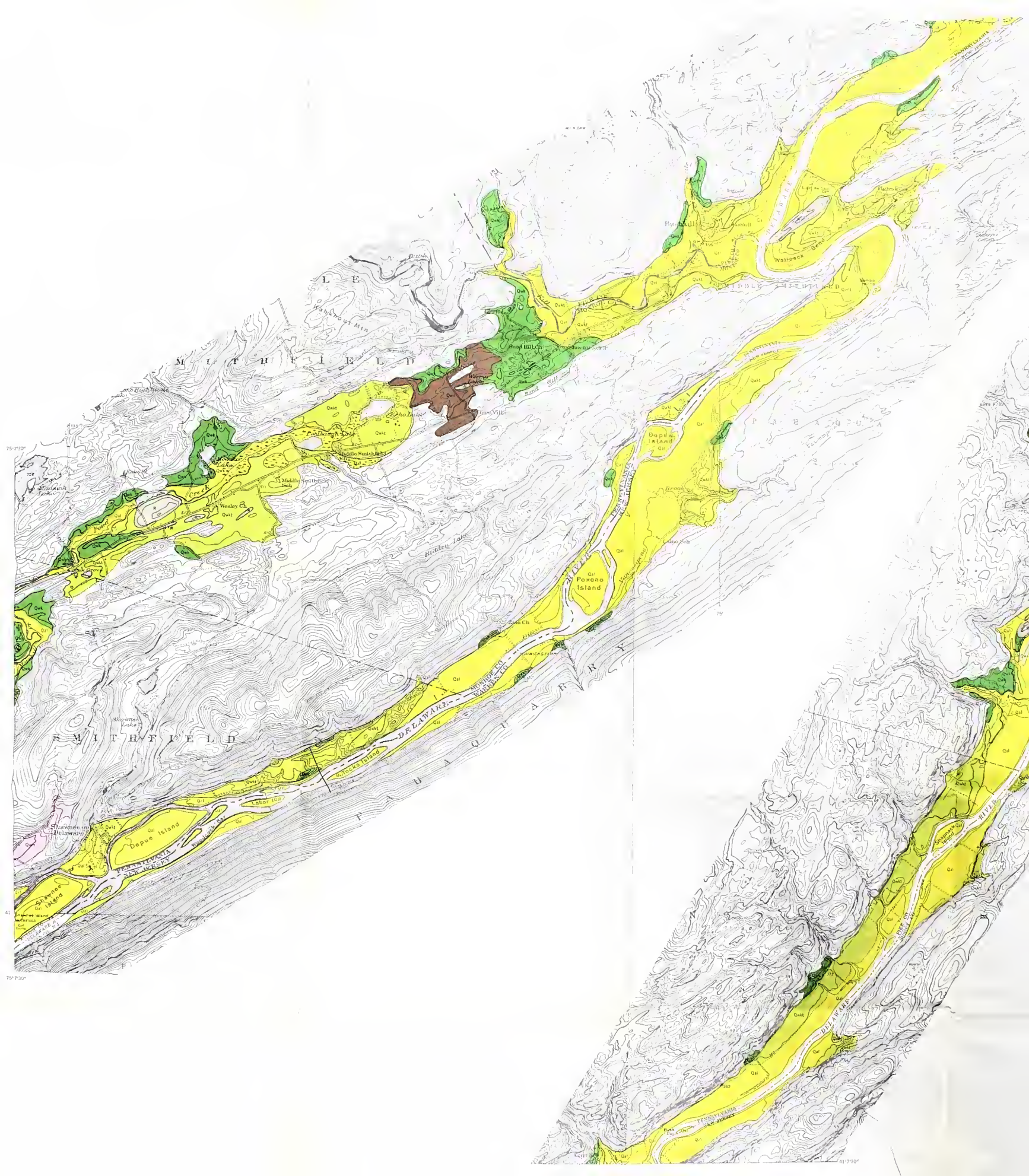   gaps.* 32nd Annual Field Conf. of Pa. Geologists Guidebook.

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GLOSSARY

Colluvium—A general term applied to loose and incoherent deposits, usually at the foot of a slope or a cliff and brought there chiefly by gravity.

Cryoturbation—Highly irregular, aimlessly contorted interpenetrating structures produced by frost action.

Drift—Any unconsolidated rock material such as boulders, till, gravel, sand, or clay, transported by a glacier and deposited by or from the ice or by or in water derived from the melting of the ice.

Glaciofluvial—Pertaining to streams flowing from glaciers or to the deposits made by such streams.

Ice-contact forms—Sand and gravel bodies such as kames, kame terraces, and eskers, deposited in contact with melting glacier ice.

Kame—A mound composed chiefly of sand or gravel, whose form is the result of original deposition modified by settling during the melting of glacier ice against or upon which the sediment accumulated.

Kame-terrace—A terrace of glacial sand and gravel, deposited between a valley ice lobe (generally stagnant) and the bounding rock slope of the valley.

Kettle hole—A bowl-shaped depression left by the melting out of an ice block which may or may not have been buried by drift.

Moraine—Drift deposited chiefly by direct glacial action, and having constructional topography independent of control by the surface on which the drift lies. The drift is usually nonsorted (i.e., till).

End moraine—A ridge-like accumulation of drift built along the margin of a glacier.

Terminal moraine—A moraine formed across the course of a glacier at its farthest advance.

Outwash—Sand and gravel deposited by meltwater streams beyond glacier ice.

Till—Nonsorted, nonstratified material, ranging in size from clay to boulders; carried or deposited directly by ice.

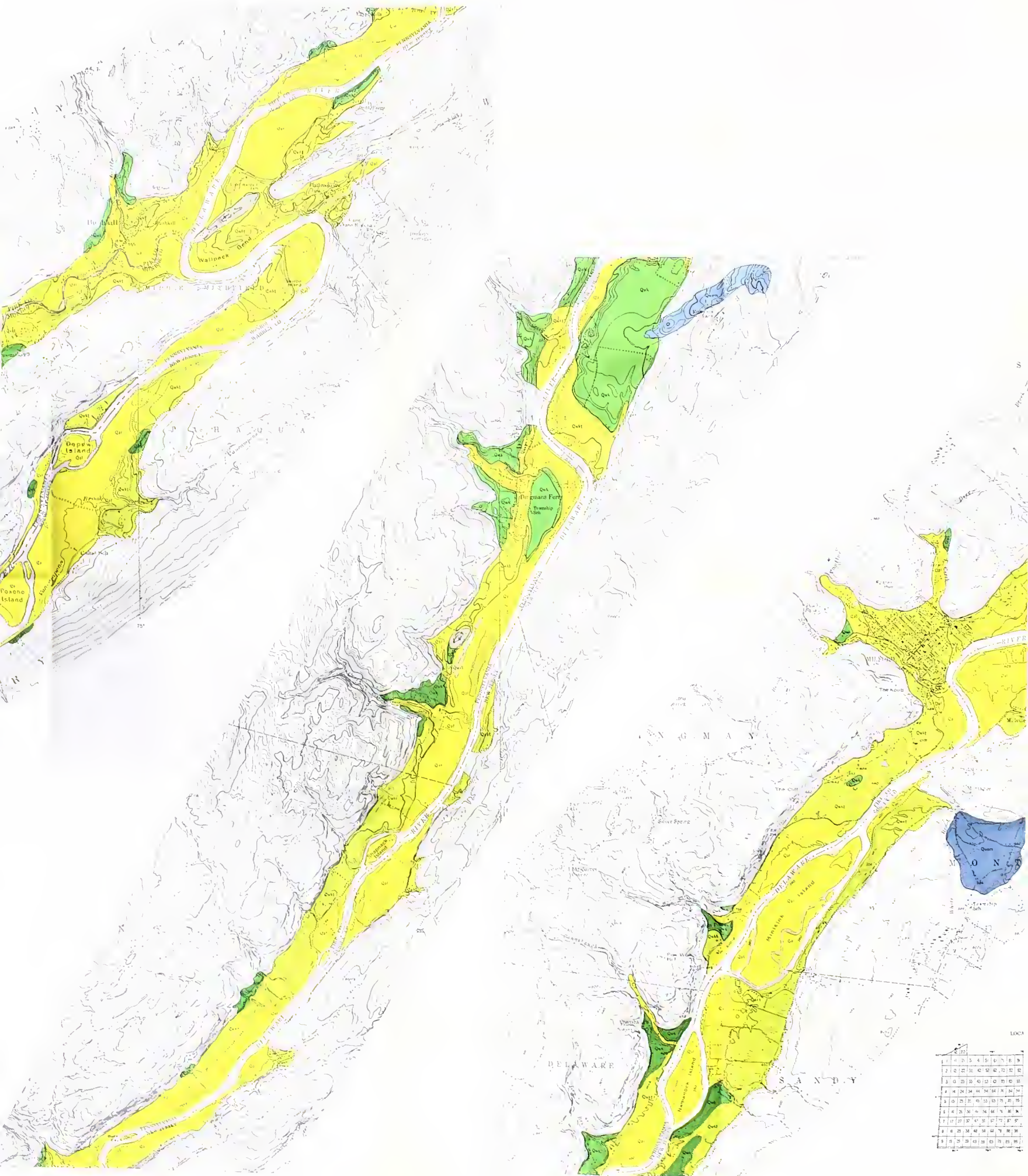*Valley train*—A long narrow body of outwash sand and gravel confined within a valley.

WARE VALLEY

FORT JERVIS

EXPLANATION

Qal	Qal	

Alluvium, terrace deposits, alluvial fans

Qkst	

Kame terrace deposits

Qk	

Kames

Qam	

Ground moraine (where mapped)

Iceblock lowland

Qem	

End moraines, from Salisbury (1902) and Minard (1968),
except small moraine near Millville, N. J.

Rock, till, and colluvium (unmapped)

Rock drumlins

Dunes

Definite contact

Approximate contact

Channel

SCALE 1:24000